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Archean (3.5 Ga) mid-ocean ridge hydrothermal system: a physico-chemical environment for early life

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To understanding the origin and evolution of life, reconstruction of geological setting for microfossil-bearing rocks and quantitative estimate of physicochemical environment of the rock formation are important. The purpose of this study is quantificational reconstructions of habitat for early life based on geological evidences obtained from a detailed geological mapping, metamorphic petrology and microthermometry and chemical composition of fluid inclusions.

The North Pole Dome (ca. 3.5 Ga) is one of the best regions in the Archean greenstone belt to investigate a tectonic evolution of the Archean greenstone belt, because this area had been subjected to only a very low-grade metamorphism. The tectonic evolution of the Archean greenstone belt was controversial issue and many different interpretations were argued. Our detailed geological and structural mapping were revealed that the North Pole Dome is an Archean accretionary complex which is characterized by duplex structures and oceanic plate stratigraphy. This interpretation is confirmed by a downward younging trend of U-Pb zircon age in felsic lava and tuffaceous cherts.

The greenstones in the North Pole Dome were divided into mid-ocean ridge basalt (MORB-type) and oceanic island basalt type (OIB-type) by their mode of occurrence and geochemical features. An Archean Seafloor hydrothermal system was identified in the MORB-type greenstones. Fossil-bearing cherts are involved with the greenstones. We recognized about 2000 silica dikes composed of fine-grained silica (<1 μm). Silica dike implies ancient hydrothermal fluid path. The greenstones are divided into three metamorphic zones (Zone A, B and C, from upper to lower stratigraphic level) by secondary mineral assemblages. Metamorphic grade increases toward the strati-

graphic lower level. Metamorphic temperature at zone B/C boundary was estimated to be 350 ˚C. Geothermal gradient for upper part (Zone A) of ancient oceanic crust was estimated by degree of maturity of carbonaceous material (CM) in bedded cherts and silica dikes, using laser Raman spectroscopy. Degree of maturity of CM is decreasing with depth from ca. 300 m to ancient seafloor (0 m). The topmost samples, however, represent relatively high degree of maturity. These suggest that ancient geothermal gradient which is gradually increased with depth, was preserved in the MORB-type greenstone unit and it was disturbed by layer parallel thrust at the top of unit.

Fluid inclusion bearing samples were identified from all over the study area. Fluid inclusions are recognized in quartz and barite vein samples. Results of microthermometry indicate that phase separation occurred in about 1000 m depth. Pressure and temperature of phase separation are estimated to be $>$ 260 bars ($>$ 1600 m of seawater depth) and 150 ˚C. This P-T condition restricted a CO_2 mole fraction (XCO_2) in hydrothermal fluid to 0.027-0.044. These values are about 5-9 times higher than present-day vent fluids collected near mid-ocean ridges. REE contents of fluid inclusions were analyzed by ICP-MS using crush and reaching method. Chondrite-normalized REE patterns show nearly flat patterns (La/Yb = 1.22-5.89), and they have a positive Eu anomaly [Eu/Eu* = 1.27-105.49; Eu* = (Sm+Nd)/2]. A positive Eu anomaly in the North Pole fluid inclusions suggests that the Archean hydrothermal fluid at mid-ocean ridge (MOR) was a relatively reductive fluid similar to that in present-day mid-ocean ridge hydrothermal fluids.

These geological and geochemical evidences suggests the environment of the Archean life evolution to be 1) a mid-ocean ridge hydrothermal system, 2) deep-sea ($>$1600 m) environment as well as modern MOR which cannot carry out photosynthesis, 3) low temperature (150 ˚C) and high-XCO_2 (at least 5 times higher than modern one) fluid was circulated, and 4) relatively reductive condition same as modern MOR hydrothermal fluid.